RF-FOCUSED SPOKE RESONATOR

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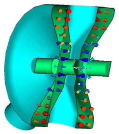
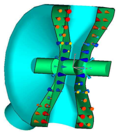
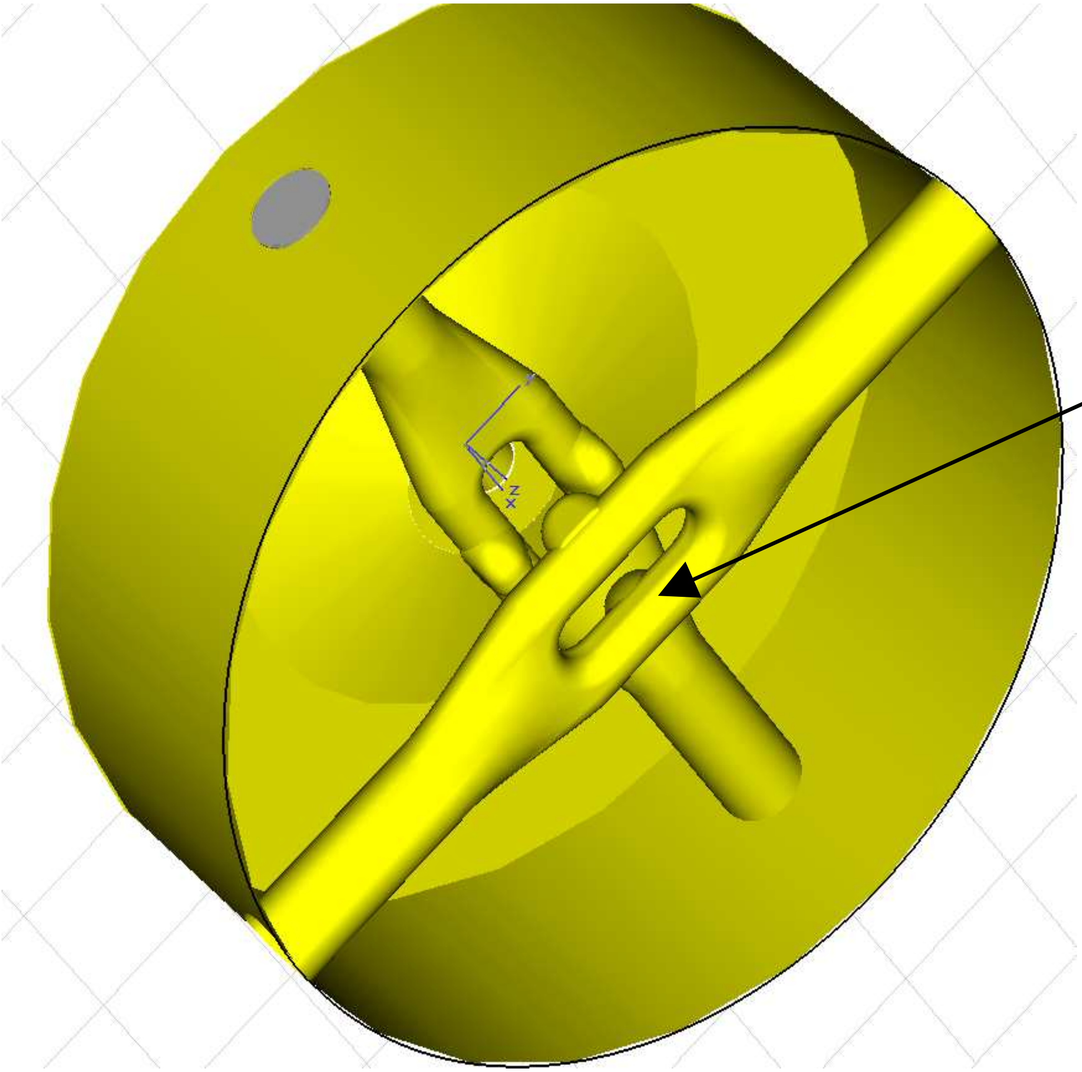


Abstract

In this paper we discuss the feasibility of using finger-like structures added to a superconducting spoke resonator cavity to superimpose a modest amount of electric quadrupole focusing onto the high axial accelerating field. The motivation for this idea is to eliminate the need for magnetic focusing elements such as solenoids between spoke cavities in a cryomodule at very low beam velocities and thereby improving the real-estate accelerating gradient by increasing the longitudinal packing factor. So far, proposed linac designs using spoke resonators at low-β have not been able to fully take advantage of the high gradients available due to the high longitudinal phase advance per period caused by engineering constraints. Preliminary results of cavity modeling and analytical calculations for the proposed structure are discussed.



Spoke Cavity Cut-Away View

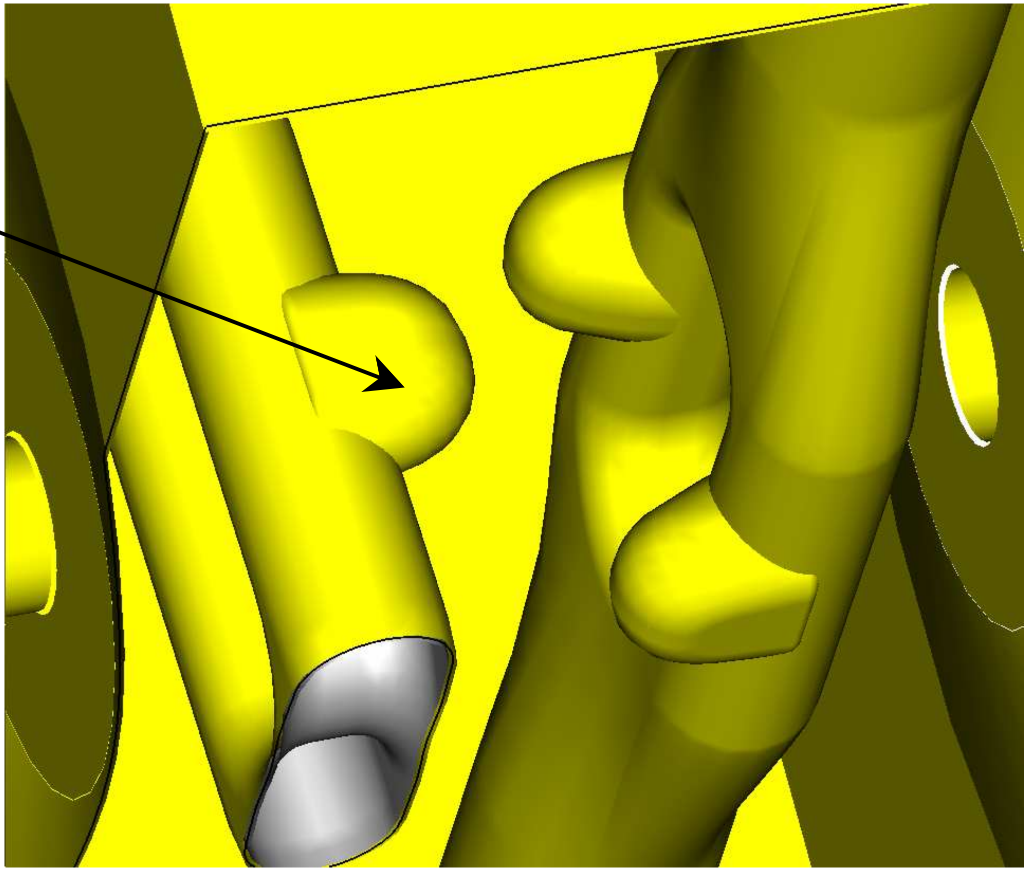


Elongated beam aperture reduces peak surface fields and cavity capacitance.

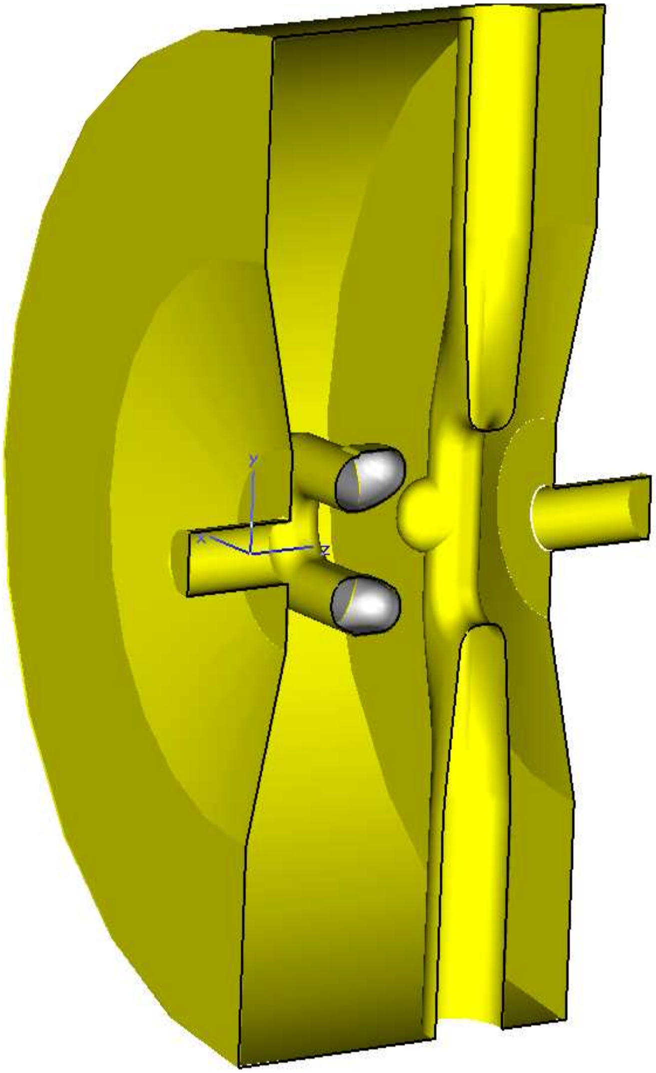
RF-Focusing Gap Geometry

“Finger” protrusions into the accelerating gap produce most of the quadrupole effect.

Focusing strength is controlled by adjusting the size of the finger-like structures.

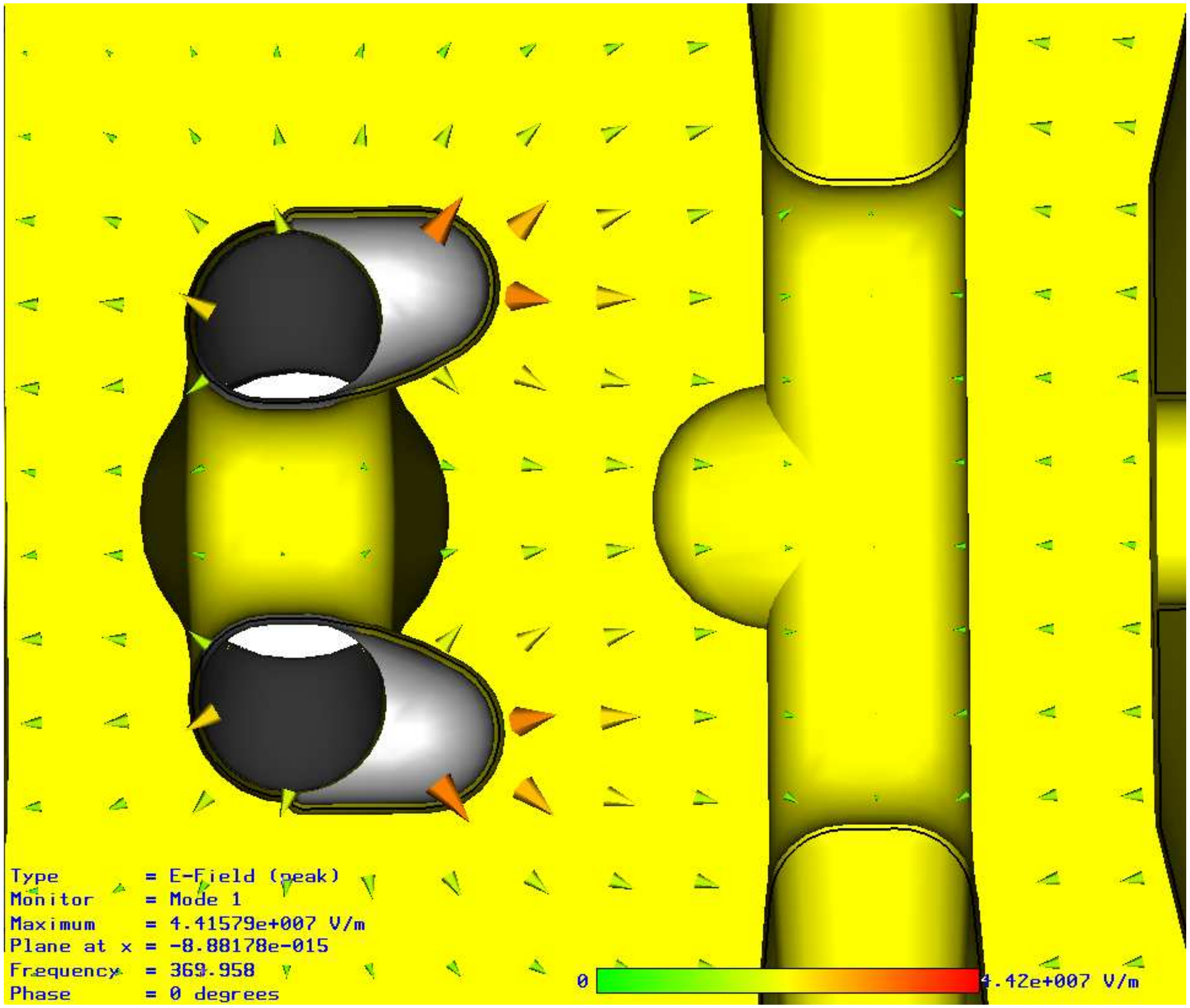


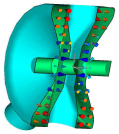
Spoke Cavity Cut-Away View



- 3-Gap Cavity
- Frequency = 350 MHz
- Geometric - β = 0.125

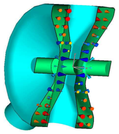
Electric Field – Microwave Studio Results
Accelerating/ Focusing Mode





Cavity Geometry Data
(left end of cavity at 0.0)

Physical length	13.39286 cm	w/o flanges
Center of 1st gap	2.232 cm	short, no quad
Center of 2nd gap	06.843 cm	long, with quad
Center of 3rd gap	11.161 cm	short, no quad
Aperture Radius	1.0 cm	



Microwave Studio Results

Transit-time Factor vs. Proton Beam Velocity

β	*Transit-Time Factor*
0.090	0.5913
0.110	0.7786
0.120	0.7990
0.140	0.7675
0.160	0.6953
0.180	0.6155
0.200	0.5404

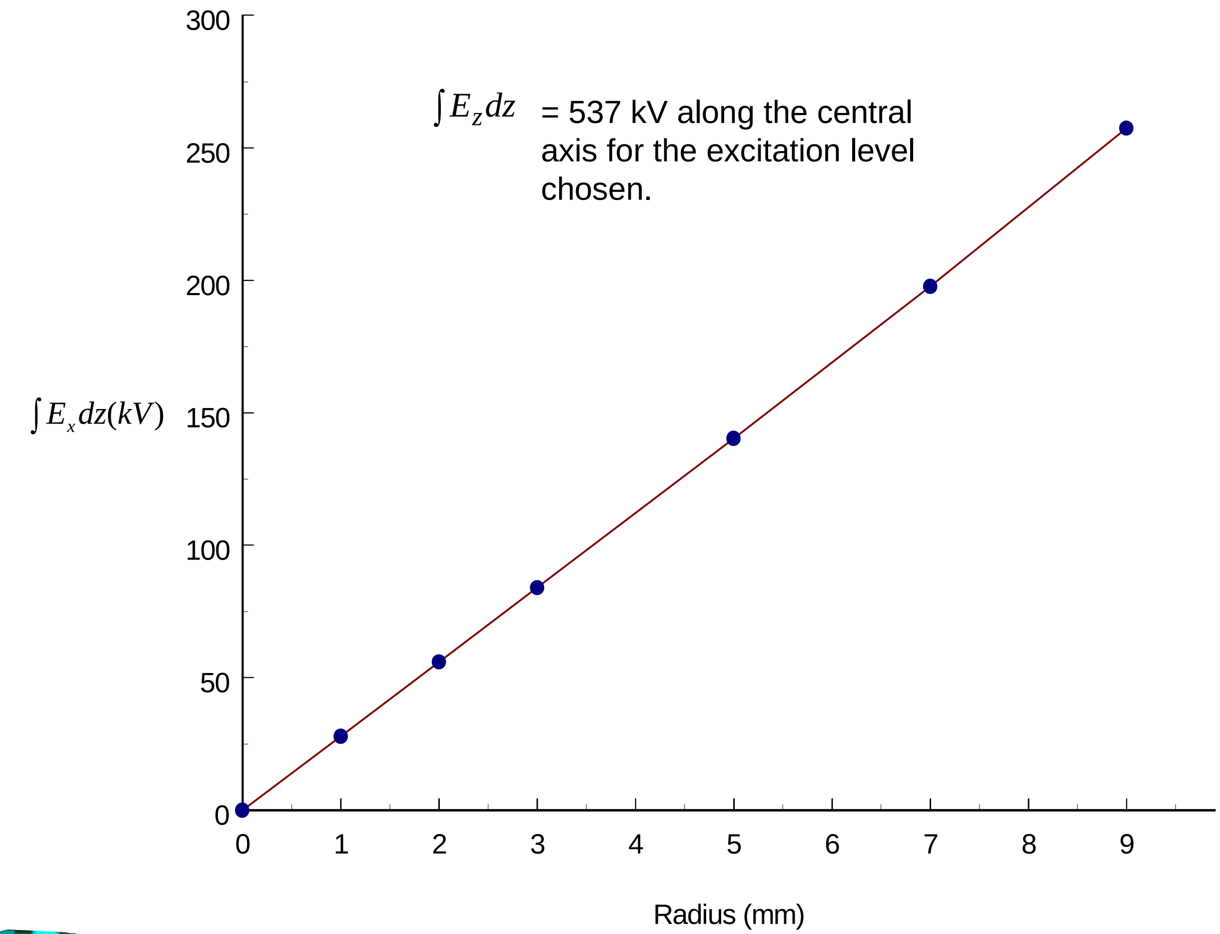
Microwave Studio Results

Cavity RF data

Q_0 *(RT)*	8907
ZT^2 / Q	311 Ω
G	44.69 Ω
Q_0 *(4K)*	7.33E+008
E_p / E_a	14.27
B_p / E_a	170 G/MV/m

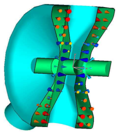
Microwave Studio Results -

$\int E_x dz$ as a function of radius



Linear variation indicates good quadrupole.

Some “roll-off” observed at r > 9mm due to weak higher-order spatial modes.

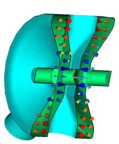


Estimate of Quadrupole Focusing Strength

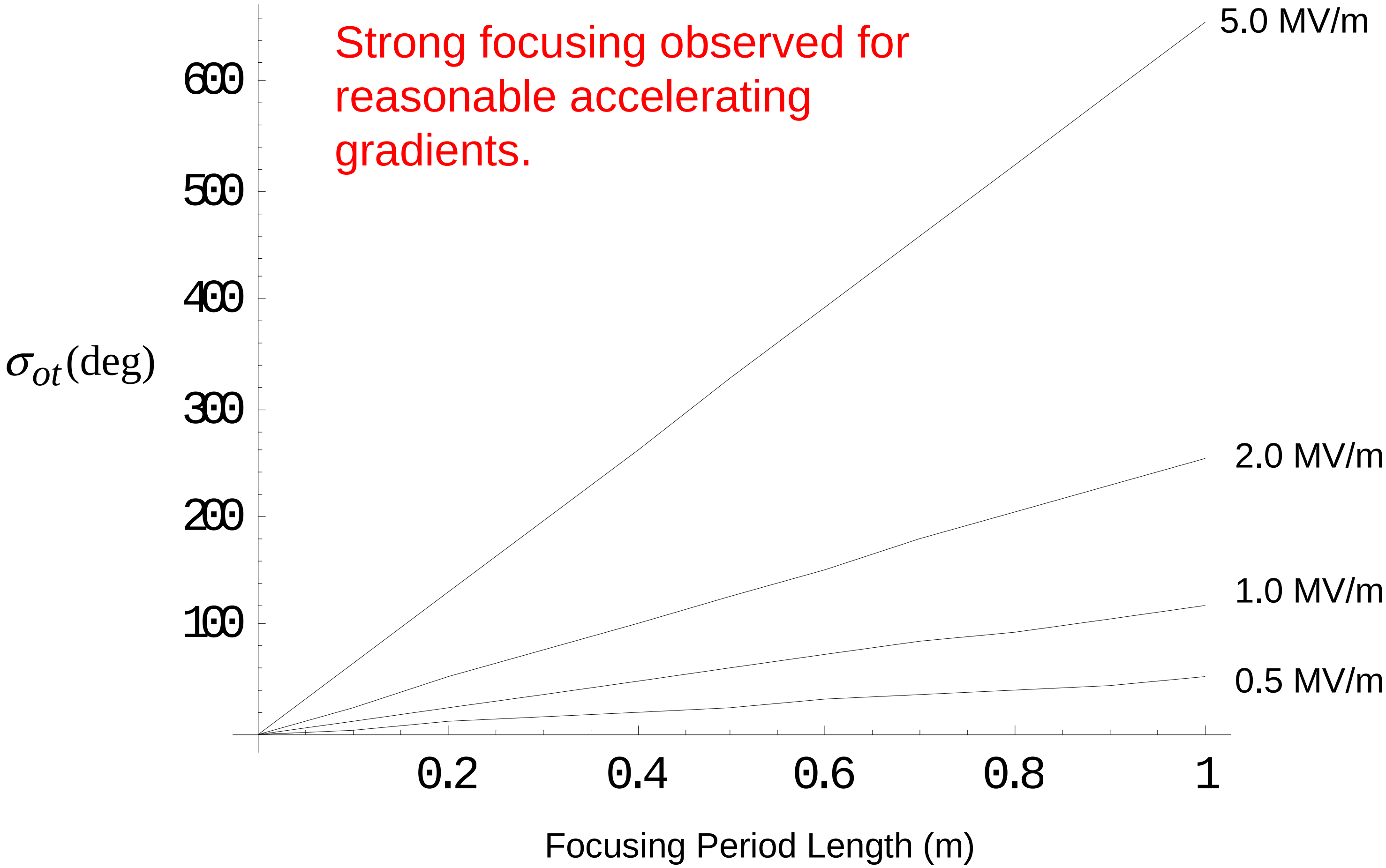
Zero-current transverse phase advance per unit length in the smooth approximation for singlet electric quadrupole focusing in the spoke cavity:

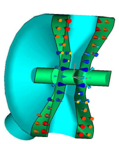
$$\left(\frac{\sigma_{0t}}{2L}\right)^2 = \left(\frac{e\int E_x dz}{2m\gamma\beta^2 c^2 a}\right)^2 - \frac{\pi e(E_0 T)\sin(-\phi)}{mc^2\lambda\gamma^3\beta^3}$$

2L " Focusing period length
Ex " Pole-tip electric field
a " Aperture radius
EoT " Axial accelerating gradient
φ " Synchronous phase



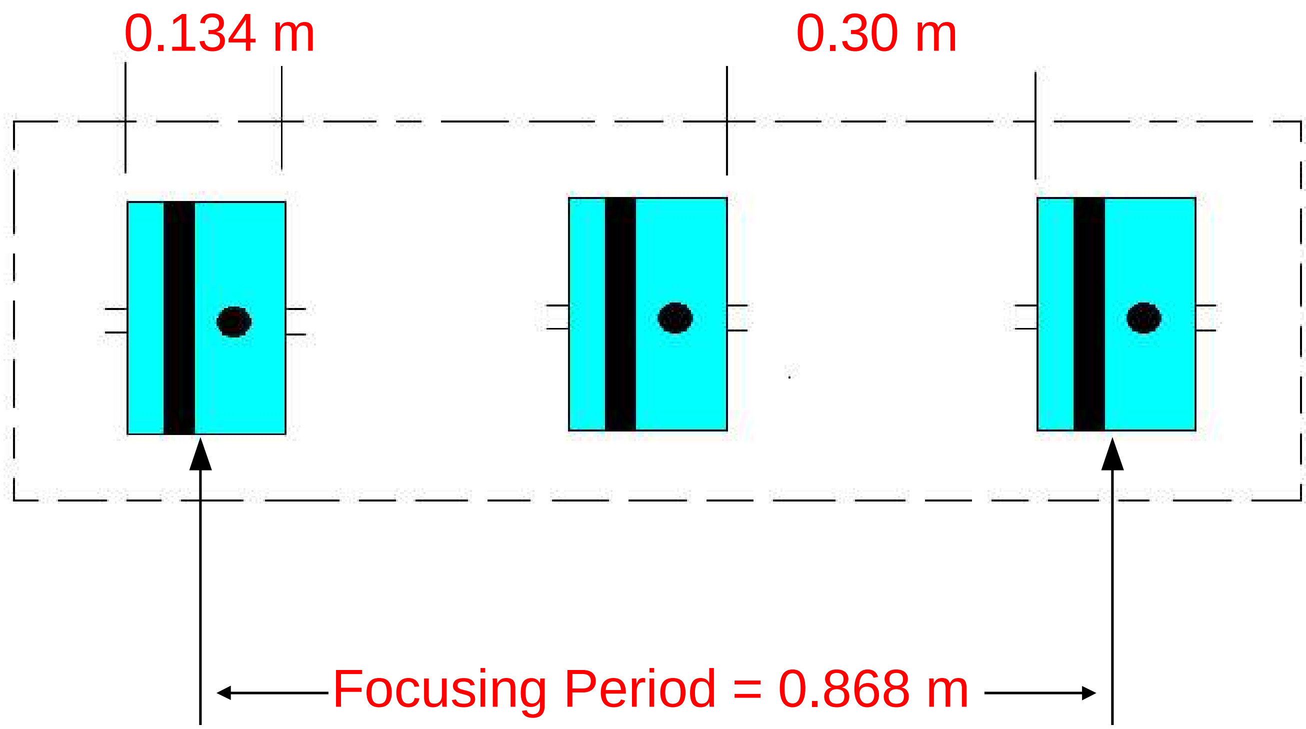
Transverse phase advance per period vs. period length for various accelerating gradients – 6.7-MeV Beam Energy





Example Focusing Lattice

(assumes short 3-gap 2-spoke cavities)



TRACE 3-D Results – Equivalent Magnetic Quadrupole

Equivalent magnetic quadrupole gradient G:

$$G = \frac{E_x}{\beta c a} \approx \frac{\int E_x dz}{\Delta z} \frac{1}{\beta c a}$$

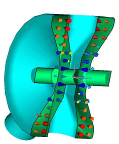
Δz = gap length of cavity (0.05357 m)

$\int E_x dz \propto E_o T$ and depends on “finger” geometry

TRACE 3-D results for example focusing lattice period (0.868 m), σ_{ot}=80°, and 6.7-MeV beam energy:

Beam Current	Normalized Transverse Emittance (π-cm-mrad)	Transverse Aperture-to-rms Beamsize Ratio
13.3 mA	0.0152	6.6
49.27 mA	0.0183	5.0
94.32 mA	0.0263	3.8

For our cavity geometry, σ_{ot}=80° @ $E_o T$ = 0.691 MV/m



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Summary & Issues

- "Proof of principle" cavity geometry explored using Microwave Studio.
- Cavity shape not yet optimized:

  - Reduce peak surface electric fields further.

  - Examine fraction of surface area at high peak surface fields.

  - Need to study higher-order spatial modes / harmonics.

  - Larger apertures possible?
- Analytical calculations indicate strong focusing possible at low-β.
- This concept shows promise for more compact low-β SC structures – longer multi-gap cavities should be studied.
- Applicable for peak beam currents of order 10 mA for present aperture and lattice using short cavities.
- Transverse and longitudinal beam parameters are coupled – Tuning Issues.
- Cavity prototype required to verify calculations!

References

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[2] P. Lapostolle, Compt. Rend. Vol. 256 (1963), p. 5294-5297.

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